Positive and negative sequence currents to improve voltages during unbalanced faults

Josep Fanals

02/2021

1   Introduction

Grid faults constitute a group of unfortunate events that cause severe perturbations in the grid. The voltages can take values below the established minimum, or on the contrary, exceed the maximum in non-faulted phases. The currents are also susceptible to vary considerably. Traditional power systems based on synchronous generators could encounter currents surpassing the nominal values, and therefore, the fault could be clearly detected. However, the increasing integration of renewables [1] supposes a change of paradigm, in which currents can be controlled but are limited so as not to damage the Isolated-Gate Bipolar Transistors (IGBT) found in the Voltage Source Converter (VSC) [2].

Transmission System Operators (TSO) are responsible for imposing requirements related to the operation under voltage sags to generators and converters [3, 4]. Such requirements are gathered in the respective grid codes. There seems to be no clear consensus on how to restore the voltage. In this sense, even if for instance the Low Voltage Ride Through (LVRT) profiles present similarities [5], analysis aimed at determining analytically the optimal injection of positive and negative sequence currents are not numerous. As far as the author is aware, only Camacho et al. offer an optimal solution regarding the injection of active and reactive powers [6].

Consequently, this work focuses on finding the most convenient positive and negative sequence currents (and not powers) to raise the voltage at the point of common coupling. First, a simple model is discussed, and then, the results are shown together with the corresponding discussion. The challenge to solve the optimization problem in a closed-form is specially described.

2   Defintion of the system

The system we are considering is formed by an ideal grid (only positive sequence voltage is present) coupled to a VSC. The model is depicted in Figure 1. The VSC will be controlled in a way that leads to an improvement in the voltage at the PCC.
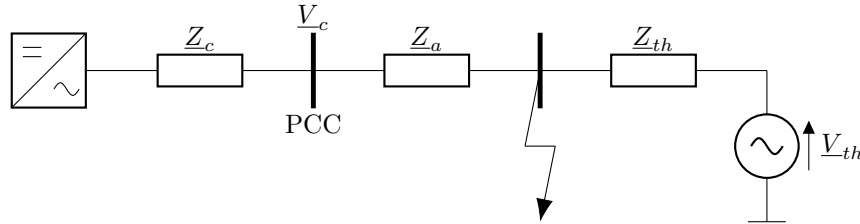

Figure 1: Single-phase representation of the simple system under a fault
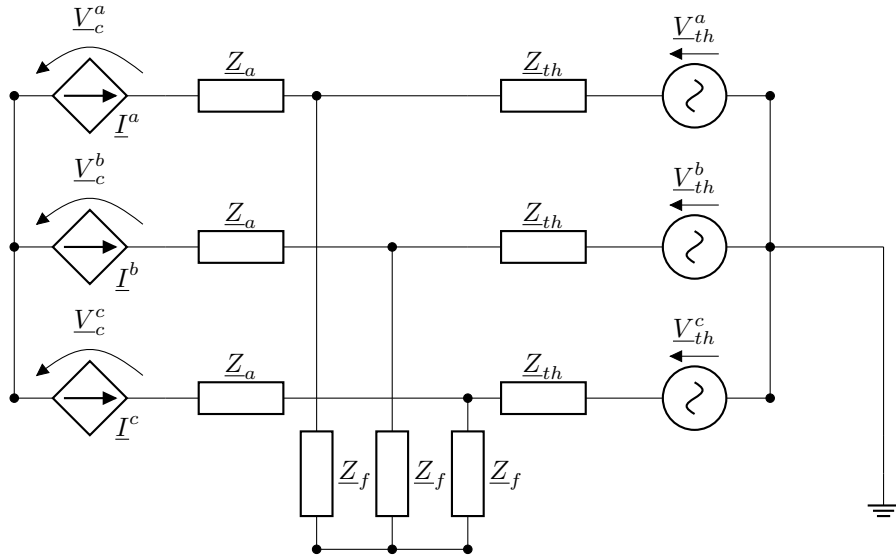
2.1 *abc* circuits
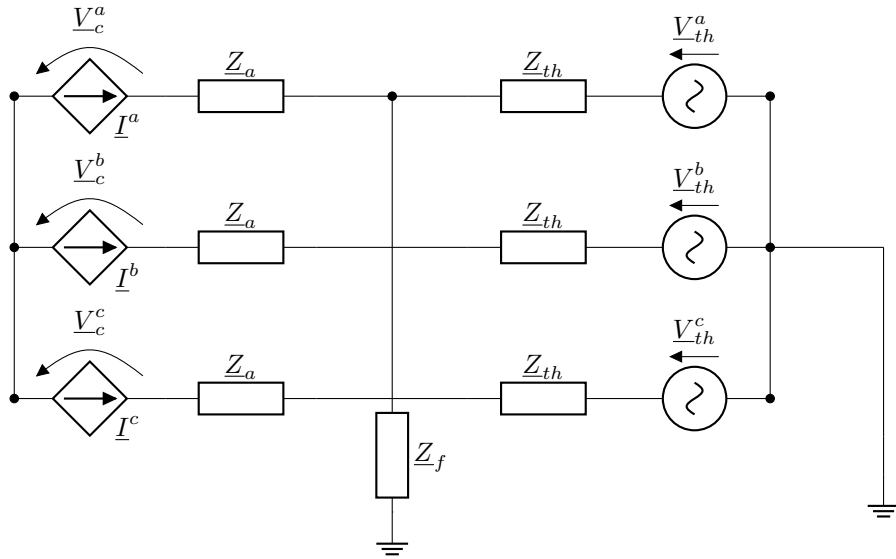

Figure 2: Balanced fault schematic

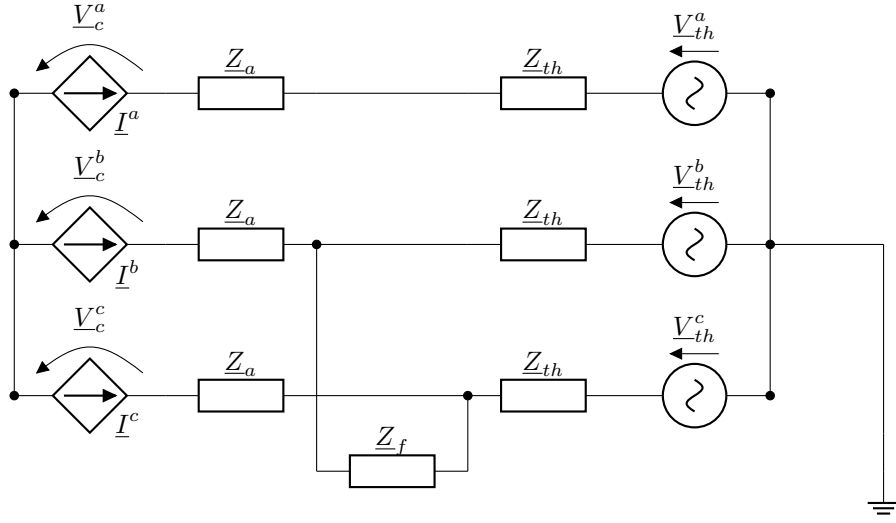Figure 3: Line to ground fault schematic
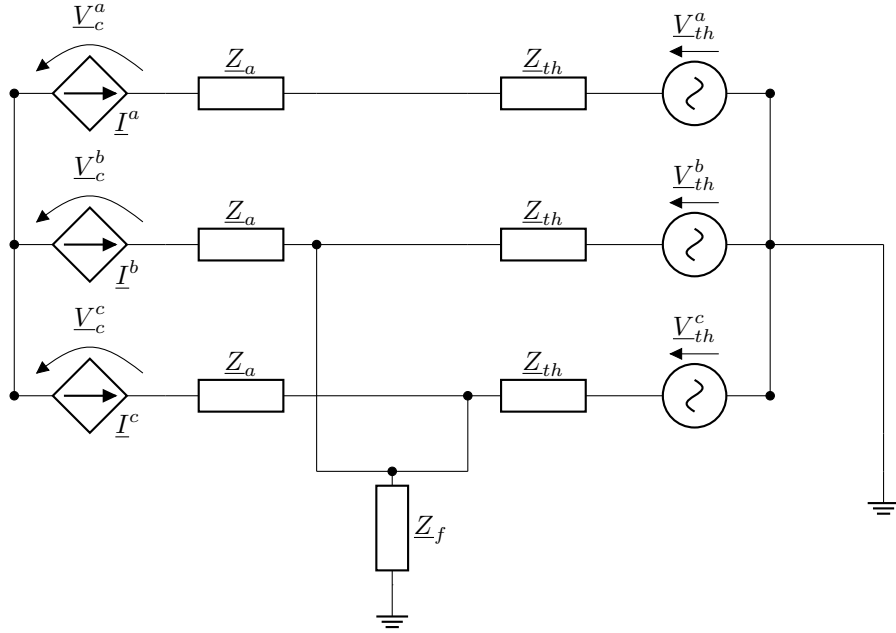
Figure 4: Line to line fault schematic

Figure 5: Double line to ground fault schematic
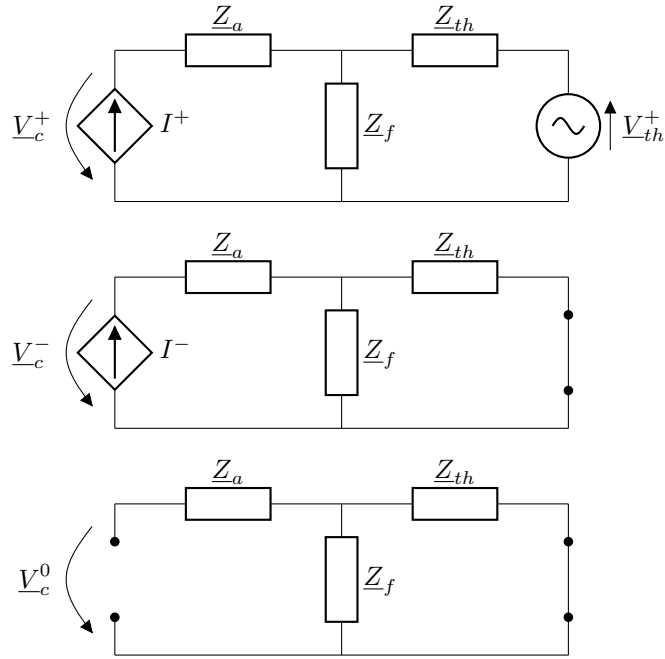
3

2.2 $+-0$ schemes

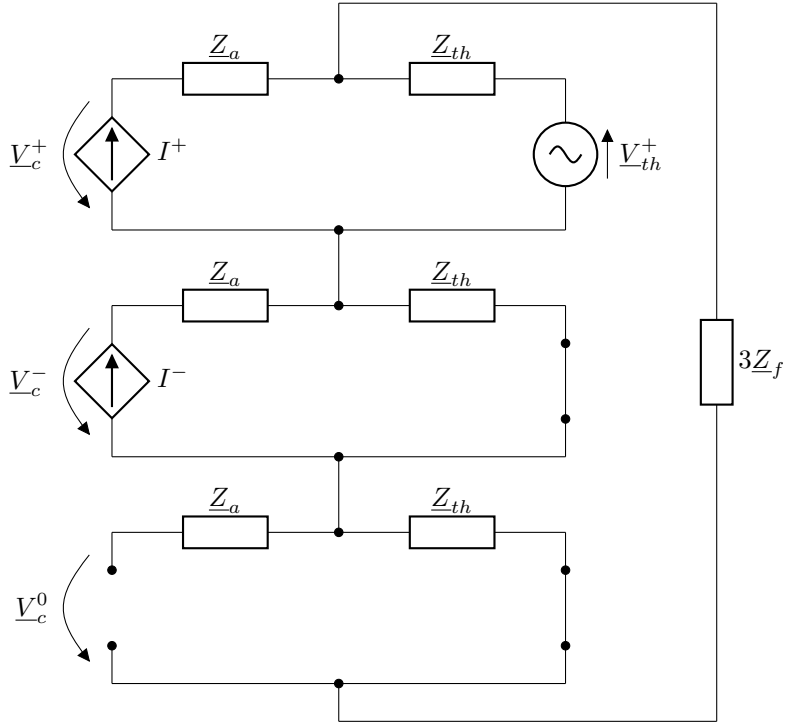Figure 6: Equivalent circuit for the balanced fault analysis

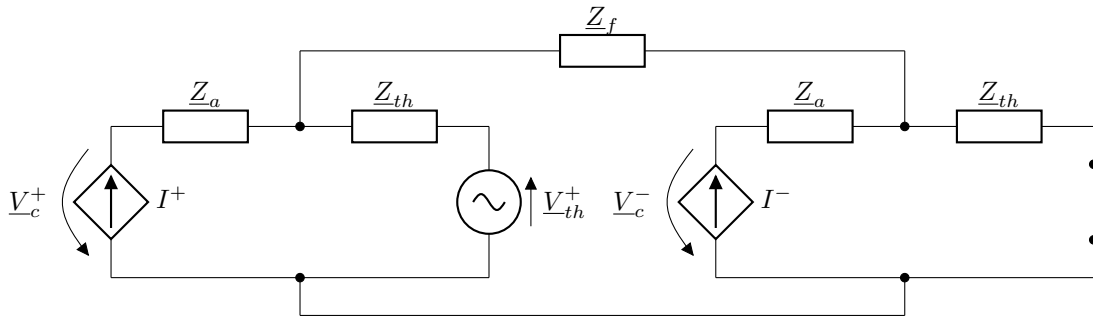Figure 7: Equivalent circuit for the line to ground fault analysis

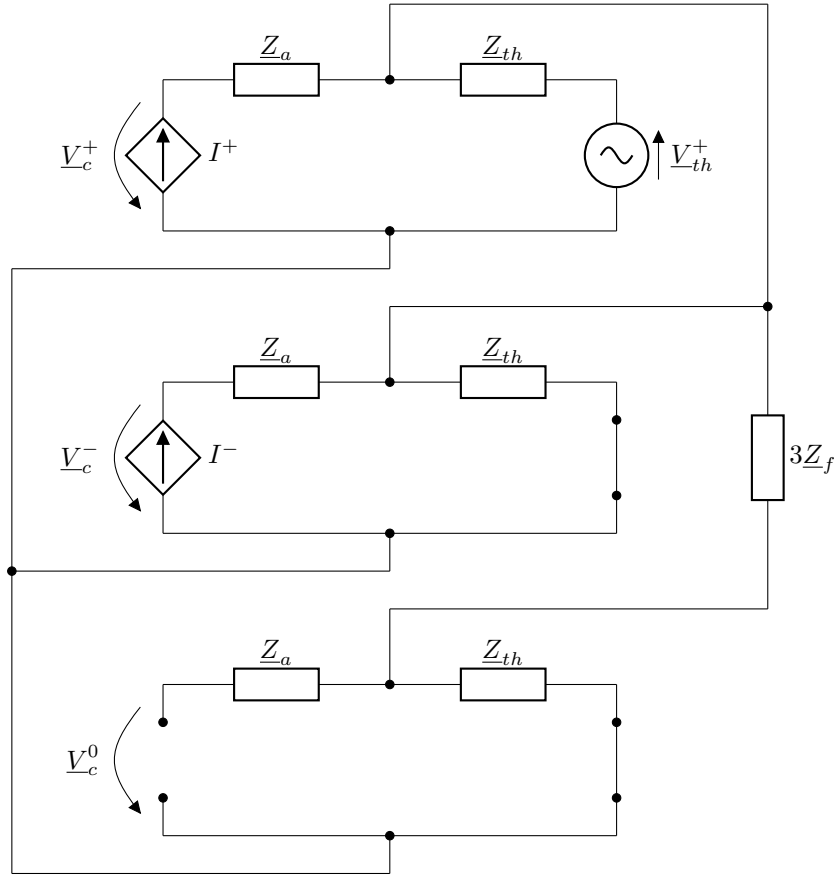Figure 8: Equivalent circuit for the line to line fault analysis

5

Figure 9: Equivalent circuit for the double line to ground fault analysis

3 Expressions

3.1 Balanced fault

$$\begin{cases} \underline{V}_c^a = \dfrac{1}{\underline{Z}_f + \underline{Z}_{th}}[\underline{V}_{th}^a \underline{Z}_f + \underline{I}_a(\underline{Z}_a \underline{Z}_{th} + \underline{Z}_{th}\underline{Z}_f + \underline{Z}_f \underline{Z}_a)] \\[2mm] \underline{V}_c^b = \dfrac{1}{\underline{Z}_f + \underline{Z}_{th}}[\underline{V}_{th}^b \underline{Z}_f + \underline{I}_b(\underline{Z}_a \underline{Z}_{th} + \underline{Z}_{th}\underline{Z}_f + \underline{Z}_f \underline{Z}_a)] \\[2mm] \underline{V}_c^c = \dfrac{1}{\underline{Z}_f + \underline{Z}_{th}}[\underline{V}_{th}^c \underline{Z}_f + \underline{I}_c(\underline{Z}_a \underline{Z}_{th} + \underline{Z}_{th}\underline{Z}_f + \underline{Z}_f \underline{Z}_a)] \end{cases} \tag{1}$$

$$\begin{cases} \underline{V}_c^+ = \dfrac{1}{\underline{Z}_f + \underline{Z}_{th}}[\underline{V}_{th}^+ \underline{Z}_f + \underline{I}^+(\underline{Z}_a \underline{Z}_f + \underline{Z}_a \underline{Z}_{th} + \underline{Z}_f \underline{Z}_{th})] \\[2mm] \underline{V}_c^- = \dfrac{1}{\underline{Z}_f + \underline{Z}_{th}}[\underline{I}^-(\underline{Z}_{th}\underline{Z}_f + \underline{Z}_a \underline{Z}_{th} + \underline{Z}_a \underline{Z}_f)] \\[2mm] \underline{V}_c^0 = 0 \end{cases} \tag{2}$$

3.2 Line to ground fault

$$\begin{cases} \underline{V}_c^a = \dfrac{1}{\underline{Z}_{th} + \underline{Z}_f}[\underline{I}_a(\underline{Z}_a \underline{Z}_{th} + \underline{Z}_a \underline{Z}_f + \underline{Z}_{th}\underline{Z}_f) + \underline{V}_{th}^a \underline{Z}_f] \\[2mm] \underline{V}_c^b = \underline{V}_{th}^b + \underline{I}_b(\underline{Z}_a + \underline{Z}_{th}) \\[2mm] \underline{V}_c^c = \underline{V}_{th}^c + \underline{I}_c(\underline{Z}_a + \underline{Z}_{th}) \end{cases} \tag{3}$$

$$\begin{cases} \underline{V}_c^+ = \underline{I}^+(\underline{Z}_a + \underline{Z}_{th}) + \underline{V}_{th}^+ - \dfrac{\underline{Z}_{th}}{3\underline{Z}_f + 3\underline{Z}_{th}}[\underline{I}^+ \underline{Z}_{th} + \underline{I}^- \underline{Z}_{th} + \underline{V}_{th}^+] \\[2mm] \underline{V}_c^- = \underline{I}^-(\underline{Z}_a + \underline{Z}_{th}) - \dfrac{\underline{Z}_{th}}{3\underline{Z}_f + 3\underline{Z}_{th}}[\underline{I}^+ \underline{Z}_{th} + \underline{I}^- \underline{Z}_{th} + \underline{V}_{th}^+] \\[2mm] \underline{V}_c^0 = -\dfrac{\underline{Z}_{th}}{3\underline{Z}_f + 3\underline{Z}_{th}}[\underline{V}_{th}^+ + \underline{I}^+ \underline{Z}_{th} + \underline{I}^- \underline{Z}_{th}] \end{cases} \tag{4}$$

3.3 Line to line fault

$$\begin{cases} \underline{V}_c^a = \underline{I}_a(\underline{Z}_a + \underline{Z}_{th}) + \underline{V}_{th}^a \\[2mm] \underline{V}_c^b = \underline{I}_b \underline{Z}_a + \dfrac{1}{(\underline{Z}_f + \underline{Z}_{th})(\underline{Z}_f + 2\underline{Z}_{th})}[\underline{I}_b(\underline{Z}_{th}\underline{Z}_f \underline{Z}_f + 2\underline{Z}_{th}\underline{Z}_{th}\underline{Z}_f + \underline{Z}_{th}\underline{Z}_{th}\underline{Z}_{th}) \\[2mm] + \underline{I}_c(\underline{Z}_{th}\underline{Z}_{th}\underline{Z}_f + \underline{Z}_{th}\underline{Z}_{th}\underline{Z}_{th}) + \underline{V}_{th}^b(\underline{Z}_f \underline{Z}_f + 2\underline{Z}_f \underline{Z}_{th} + \underline{Z}_{th}\underline{Z}_{th}) + \underline{V}_{th}^c(\underline{Z}_{th}\underline{Z}_f + \underline{Z}_{th}\underline{Z}_{th})] \\[2mm] \underline{V}_c^c = \underline{I}_c \underline{Z}_a + \dfrac{1}{\underline{Z}_f + 2\underline{Z}_{th}}[\underline{I}_c(\underline{Z}_{th}(\underline{Z}_f + \underline{Z}_{th})) + \underline{V}_{th}^c(\underline{Z}_f + \underline{Z}_{th}) + \underline{I}_b \underline{Z}_{th}\underline{Z}_{th} + \underline{V}_{th}^b \underline{Z}_{th}] \end{cases} \tag{5}$$

$$\begin{cases} \underline{V}_c^+ = \underline{V}_{th}^+ + \underline{I}^+(\underline{Z}_a + \underline{Z}_{th}) - \dfrac{\underline{Z}_{th}}{2\underline{Z}_{th} + \underline{Z}_f}[\underline{V}_{th}^+ + \underline{I}^+ \underline{Z}_{th} - \underline{I}^- \underline{Z}_{th}] \\[2mm] \underline{V}_c^- = \underline{V}_{th}^+ + \underline{I}^+ \underline{Z}_{th} + \underline{I}^- \underline{Z}_a - \dfrac{\underline{Z}_{th} + \underline{Z}_f}{2\underline{Z}_{th} + \underline{Z}_f}[\underline{V}_{th}^+ + \underline{I}^+ \underline{Z}_{th} - \underline{I}^- \underline{Z}_{th}] \\[2mm] \underline{V}_c^0 = 0 \end{cases} \tag{6}$$

3.4 Double line to ground fault

$$
\begin{cases}
\underline{V}_c^a = \underline{I}_a(\underline{Z}_a + \underline{Z}_{th}) + \underline{V}_{th}^a \\
\underline{V}_c^b = \underline{I}_b\underline{Z}_a + \dfrac{\underline{Z}_{th}\underline{Z}_f(\underline{I}_b + \underline{I}_c) + \underline{Z}_f(\underline{V}_{th}^b + \underline{V}_{th}^c)}{2\underline{Z}_f + \underline{Z}_{th}} \\
\underline{V}_c^c = \underline{I}_c\underline{Z}_a + \dfrac{\underline{Z}_{th}\underline{Z}_f(\underline{I}_b + \underline{I}_c) + \underline{Z}_f(\underline{V}_{th}^b + \underline{V}_{th}^c)}{2\underline{Z}_f + \underline{Z}_{th}}
\end{cases}
\tag{7}
$$

$$
\begin{cases}
\underline{V}_c^+ = \underline{I}^+\underline{Z}_a + \dfrac{\underline{Z}_{th} + 3\underline{Z}_f}{3\underline{Z}_{th} + 6\underline{Z}_f}[\underline{I}^+\underline{Z}_{th} + \underline{I}^-\underline{Z}_{th} + \underline{V}_{th}^+] \\
\underline{V}_c^- = \underline{I}^-\underline{Z}_a + \dfrac{\underline{Z}_{th} + 3\underline{Z}_f}{3\underline{Z}_{th} + 6\underline{Z}_f}[\underline{I}^+\underline{Z}_{th} + \underline{I}^-\underline{Z}_{th} + \underline{V}_{th}^+] \\
\underline{V}_c^0 = \dfrac{\underline{Z}_{th}}{3\underline{Z}_{th} + 6\underline{Z}_f}[\underline{I}^+\underline{Z}_{th} + \underline{I}^-\underline{Z}_{th} + \underline{V}_{th}^+]
\end{cases}
\tag{8}
$$

References

[1] Ahmed Sharique Anees. "Grid integration of renewable energy sources: Challenges, issues and possible solutions". In: *2012 IEEE 5th India International Conference on Power Electronics (IICPE)*. IEEE. 2012, pp. 1–6.

[2] AF Abdou, Ahmed Abu-Siada, and HR Pota. "Improving the low voltage ride through of doubly fed induction generator during intermittent voltage source converter faults". In: *Journal of Renewable and Sustainable Energy* 5.4 (2013), p. 043110.

[3] Marina Tsili and S Papathanassiou. "A review of grid code technical requirements for wind farms". In: *IET Renewable power generation* 3.3 (2009), pp. 308–332.

[4] Florin Iov et al. "Mapping of grid faults and grid codes". In: (2007).

[5] JF Conroy and R Watson. "Low-voltage ride-through of a full converter wind turbine with permanent magnet generator". In: *IET Renewable power generation* 1.3 (2007), pp. 182–189.

[6] Antonio Camacho et al. "Positive and negative sequence control strategies to maximize the voltage support in resistive–inductive grids during grid faults". In: *IEEE Transactions on Power Electronics* 33.6 (2017), pp. 5362–5373.